Inviscid Simulations of Interacting Flags and Falling Sheets

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Abstract

We present a fluid dynamics video showing simulations of flexible bodies flapping and falling in an inviscid fluid. Vortex sheets are shed from the trailing edges of the bodies according to the Kutta condition. For interacting flags, a sampling of synchronous and asynchronous states are shown. For falling flexible sheets, the basic behavior is a repeated series of accelerations to a critical speed at which the sheet buckles, and rapidly decelerates, shedding large vortices. Examples of persistent circling, quasi-periodic flapping, and more complex trajectories are shown.

The video is shown in high-resolution and low-resolution files. The first half of the video shows interacting flags, and the second half shows falling flexible sheets.

1 Simulations of Interacting Flags

The video begins with "**Example of asynchronous dynamics for side-by-side flags**." The flags are green solid lines, and the vortex sheets they shed are blue dotted lines. The leading edges are spaced apart by a distance equal to 60% of the flags' lengths. At this close distance, the flags do not synchronize. Their ends interact strongly, which destabilizes any trend toward synchrony. The flags do flap nearly out of phase for sustained periods, and when the separation distance is increased to 90% of the flags' lengths,

they flap synchronously and with opposite phase. Further increases in distance yield a monotonic variation of phase, with the flags flapping in phase at a separation of 2.5 flag lengths.

The next segment is "**Example of synchronous dynamics for tandem flags**." The leader flag is green and the follower flag is orange. The follower intercepts the vortex wake of the leader, which passes along the follower tangentially, and influences its vortex shedding. The two wakes merge, and the additional stimulation from the leader wake causes the follower to flap with an amplitude and drag which are larger than that for the leader.

The spacing between the leader and follower is increased in the subsequent clip, "**Example of asynchronous dynamics for tandem flags**." This spacing does not allow the same-signed vorticity to coincide when the flags' wakes meet. The follower flaps irregularly, and with an amplitude and drag which are smaller on average than in the synchronous case, and close to that of the leader. The black stars show point vortices, which approximate the vortex sheets downstream for computational efficiency.

2 Simulations of Falling Sheets

The second topic of the video is introduced by the clip entitled "**Falling flexible sheet trajectories: Example of buckling while falling**." The moving solid orange line is a flexible fiber, falling under gravity, and shedding a vortex sheet (blue line) from its trailing edge. The two control parameters are the sheet density normalized by fluid density (R_1, 0.3 here) and the sheet rigidity normalized by fluid inertia (R_2, 2.4 here). The basic behavior is a repeated series of accelerations to a critical speed at which the sheet buckles, and rapidly decelerates, shedding large vortices. The still frames which surround the moving picture give sample trajectories for many different initial falling angles and different sheet rigidities. These paths show a diversity of punctuated falling and circling behaviors (circling is seen for R_2 equal to 10 and above). The still frame labeled "$R_1 = 0.3$, $R_2 = 2.4$" shows in light blue the trajectory traced by the orange fiber as it falls.

The final clip, "**Falling flexible sheet trajectories: Examples of quasi-periodic flapping**," shows an alternative falling behavior. For a range of smaller R_1 and R_2 (two examples are shown), the body flaps steadily as it falls. The example to the left is an asymmetric flapping state. The example to the right shows symmetric flapping with a simple period. The drag encountered by these flapping bodies balances the acceleration from gravity. The still panels again show examples of different falling trajectories

as parameters are varied. The blue trajectories in the still frame labeled "$R_1 = 0.3$, $R_2 = 1$"correspond to states of flapping while falling, encountered for many different initial falling angles at these parameter values.